Journal of Natural Resource Conservation and Management
Vol. 5, No. 1, pp 32-36, 2024
doi:

Dielectric properties of barley seed (*Hordeum vulgare*) in the radio frequency range

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Received : February 24, 2024
Revised : April 06, 2024
Accepted : April 06, 2024
Published : June 30, 2024

ABSTRACT

The dielectric parameters of hygroscopic materials such as seed and grains are changing with the frequency of applied electric field. The dielectric parameters of these hygroscopic materials have various practical applications such as in determining instantaneous moisture content of seed lots during the harvesting, processing and storage. This paper presents the dielectric properties of barley seed (*Hordeum vulgare*) over the radio frequency range of 5-10000 kHz, measured by the Hewlett-Packard (HP-4194A) impedance gain phase analyzer over the moisture content range of 4.1-21.1%, density range of 0.649-0.612 gm/ cm^{-3} and temperature range of 30-45^{o}C. The moisture and dielectric constant or permittivity correlation showed that 10000 kHz radio frequency could be used for determine moisture content of barley seeds.

Keywords: Dielectric constant, hygroscopic material, radio frequency, electric field, seed and grains

INTRODUCTION

The dielectric properties of describe the interaction of a material with an applied electric field. These interacting properties are the dielectric constant ε′ and the dielectric loss factor ε″, the real and imaginary part of a relative complex permittivity ε*, which is expressed as

$$\varepsilon^* = |\varepsilon^*| e^{-i\delta} = \varepsilon' - j\varepsilon''$$

where δ is called loss angle of the dielectric, given as

$$\delta = \tan^{-1} (\varepsilon'/\varepsilon'')$$

The dielectric constant ε′ is the measure of electromagnetic energy stored in material, while the dielectric loss factor ε″ describes energy dissipation rate in the material (Gracia *et al.*, 2001). The dielectric properties of hygroscopic biological material such as seed and grains are depending on the moisture content and the ways the water is held in the seed structure. The dielectric properties also vary with frequency of applied electric field. This variation over a wide range of frequency spectrum is called *dielectric dispersion* or dielectric relaxation spectrum (DRS), and the mechanism responsible for this dispersion is called relaxation. The DRS has many applications in agro processing industries. The values of dielectric parameters are used for real-time moisture determination of hygroscopic seed and grains lots.

Agriculture has been and will continue to be the major lifeline of Indian economy. Barley grain is used primarily as a nutritious human food in various forms such as unleavened bread. Its common grain has high fiber content. It is consumed in food and used to brew alcoholic beverages worldwide. The fiber in barley might lower cholesterol, blood sugar, and insulin levels. It also seems to slow stomach emptying which could keep blood sugar stable and help to control appetite. Therefore, precision farming and quality control of barley seed and grains at the time of harvesting, transportation and storage are important. The quality control of the grains and seeds can be done by knowing the dielectric properties. Knowledge of dielectric properties over the radio frequency range is useful for online instantaneous determination of moisture content. All the above are needed information on dielectric parameters values over radio frequency and microwave. This paper presents the dependence of dielectric parameter on frequency, temperature and moisture content of barley seed over the frequency range of 5-10000 kHz and their correlation with moisture content.

MATERIALS AND METHODS

The barley seed (*Hordeum vulgare*) of variety BR-31 was selected for study. To investigate the effect of moisture content and dielectric parameters, the samples of different moisture levels were required. Therefore, the initial moisture content of each sample was determined as per the ASAE standard (1999) by drying triplicate samples each of 10 g in forced air-oven at 130 °C for few hours till the weight become constant. This method relied on weight loss and the moisture content on a wet basis. It was not possible to obtain grain samples of desired moisture content; therefore, few samples were conditioned either by adding moisture or by drying. For obtaining moisture level greater than the initial level, distilled water was added to the samples in glass jars. These jars were sealed and stored at 4 °C for at least 72 hours (Agrwal, 1999). The jars were frequently agitated to get uniform moisture samples. For a moisture level lower than the initial level, sample was dried in open air for several hours to reach the lower desired moisture level. Before each measurement, samples were allowed to equilibrate at the room temperature for few hours. Hewlett-Packard (HP-4194A) impedance gain phase analyzer was used for determining the dielectric properties. The instrument employs microprocessor controlled built in bridges and resonant circuits. This analyzer was equipped with a test fixture (16047D) and a specially designed coaxial cylindrical sample holder.

The coaxial sample holder was filled with grain uniformly by following consistent filling procedure so that seed kernel could get natural course of adjustment and normal course of density leaving minimum air-filled space in between. The sample holder was then placed inside the temperature-control chamber. The capacitance and dissipation factors were measured over the temperature range of 30°- 45°C, as normally seed exist at this temperature range. After the completion of each measurement over the desired temperatures, the grain sample was poured out of the sample holder to measure bulk density. A high and a low moisture sample in general might not be in equilibrium with the ambient condition of the laboratory; therefore, moisture determination was made before and after each series of measurement to detect any change in moisture content level.

RESULTS AND DISCUSSION

Frequency dependence of dielectric constant

The values of dielectric constant, dielectric loss factor of selected seed at discrete frequencies, different moisture levels and densities over the temperature range of 30– 45 °C were determined experimentally. The pattern of dependence of dielectric constant of barley seed on various factors are shown in Fig. 1-3.

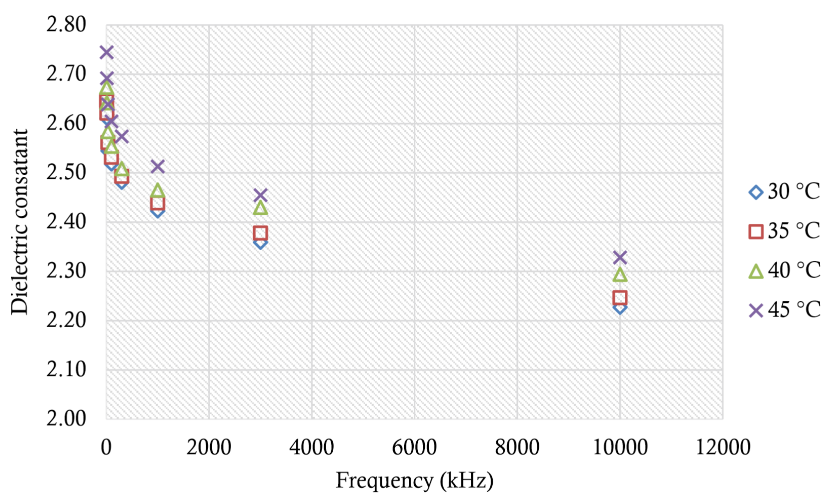

Fig. 1. Dielectric constant of barley at moisture content 4.1% and bulk density 0.649 g/cm³

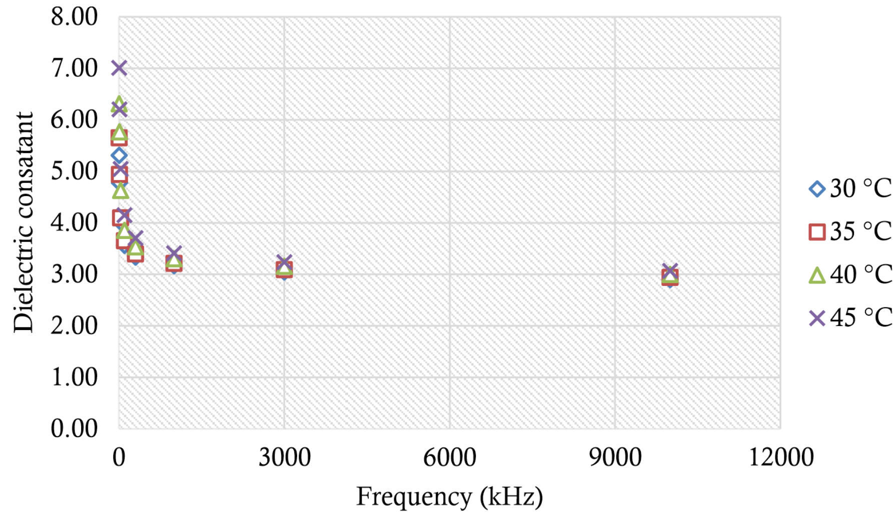

Fig. 2. Dielectric constant of barley at moisture content 11.0% and bulk density 0.630 g/cm^3

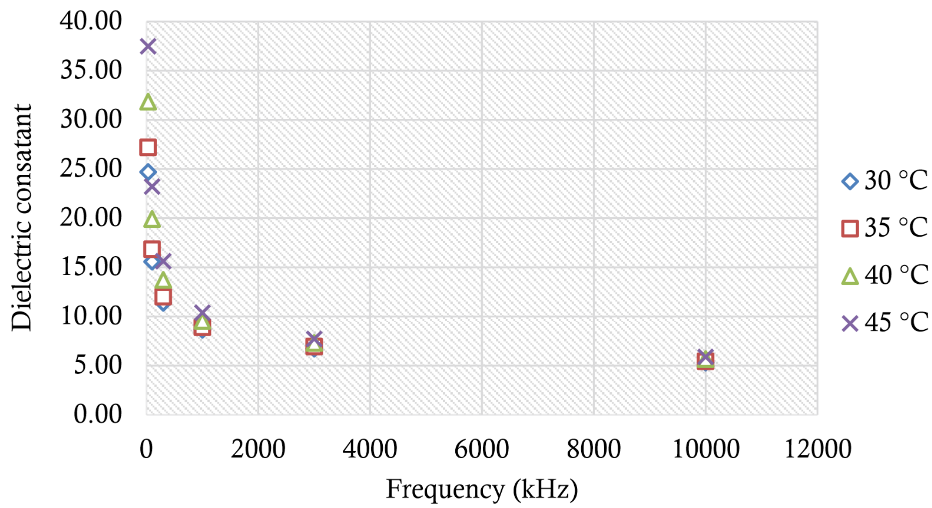

Fig. 3. Dielectric constant of barley at moisture content 20.1% and bulk density 0.612 g/cm^3

Interpterion of Fig. (1-3) showed that the dielectric constant decreased with increase in frequency at all moisture content; however, the rate of change of dielectric constant with frequency was different. This trend could be attributed to the facts that the relaxation mechanism operating at different frequencies were different in nature. A high value of dielectric constant at low frequency was due to the electric polarization and the artifact of instrument (Magario and Yamaura, 1988). Nelson (1979) reported a similar behaviour in corn between the moisture content 10-50% over the frequency range of 1- 11 GHz, and Jones *et al.* (1978) reported a similar behaviour in wheat and corn over the frequency range of 1-20000 kHz.

Moisture dependence of dielectric constant

The Fig. 1-3 shows the moisture dependence of dielectric constant of barley seed. The interpretation of the plots revealed that the dielectric constant increased with increase in moisture content at a given temperature and frequency; however, the rate of increase in dielectric constant was high at low frequencies. This behaviour was obvious in view of the relaxation mechanism. At low moisture content, i.e., below 5%, the dielectric constant had smaller values. This was due to strong bound state of water, the monolayer, where distance between a water molecule and the cell wall was very small and the attraction force between them was very strong. A strong force prevented the water molecule from

Table 1. Values of dielectric constant of barley seed over the radio frequency range of 5-10000 kHz

Moisture content (%) wet basis	Bulk density (gm/cm^{-3})	Frequency range (kHz)	Dielectric constant range (relative permittivity)
4.1	0.649	5-10000	2.674-2.274
5.5	0.648	5-10000	2.973-2.481
11.0	0.635	5-10000	6.068-2.974
16.1	0.630	5-10000	36.204-4.376
20.1	0.612	5-10000	81.602-5.579

aligning into the field direction and therefore the effective dielectric constant was small. As moisture content level was increased, the increase in dielectric constant enhanced. This behavior was due to the change in bound water state, i.e., from first monolayer to second multilayer type. A sharp increase in dielectric constant was noticed at all the frequencies, as moisture content crossed above 11.1%. This behaviour could be ascribed to the transition of bound water state to a free state water, i.e., from a second type multilayer to a third type osmotic tension transition.

Temperature dependence of dielectric constant

The Fig. (1-3) showed that at low moisture content the dielectric constant increased with increase in temperature at all the frequencies and change in dielectric constant value is high. But even at high moisture level and at high frequency the temperature effect on dielectric constant was almost negligible. Lawrence *et. al.* (1992) reported similar variations in the temperature range of 0-40 °C for pecan.

Bulk density dependence of dielectric constant

The dependence of dielectric constant on bulk density of barley seed at 1000 kHz and 10000 kHz are shown in Fig.4. The interpretation of the plots showed that the dielectric constant decreased with increase in bulk density and the rate of change at high frequency was low compared to rate of change at a low frequency. This trend showed that the dielectric constant was less affected by the bulk density at a high frequency.

Correlation between dielectric constant and moisture level

The behaviour of dielectric constant at different moisture levels and at 100 kHz, 1000 kHz and 10000 kHz frequencies are shown in Fig. 5. The interpretation of different curve showed that the R^2 value at 100 kHz, 1000 kHz and 10000 kHz under linear fit curves were 0.894, 0.903 and 0.951, respectively. Therefore, moisture content of barley seed could be estimated using radio frequency operating mechanism at 10000 kHz with inclusion of density correction factor, as per bulk density

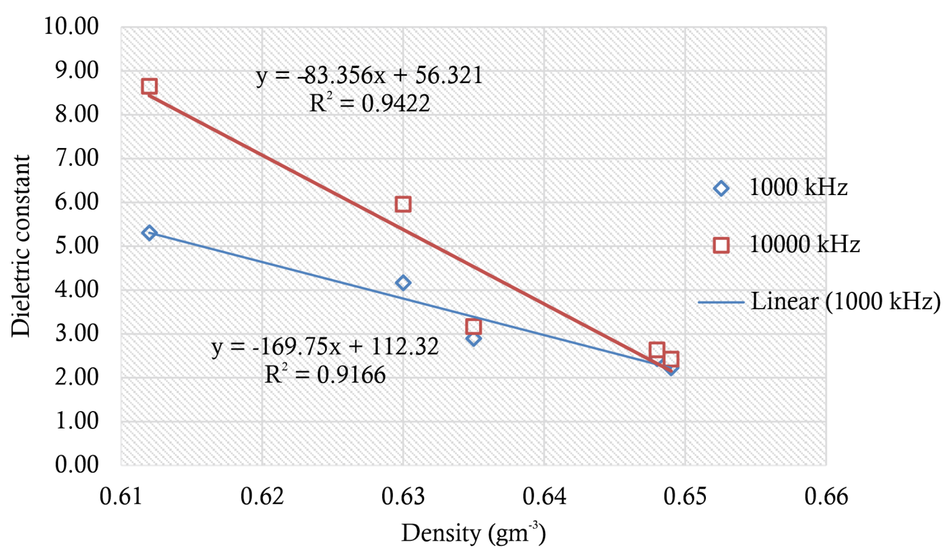

Fig. 4. Variation of dielectric constant of with barley grain density at different frequencies

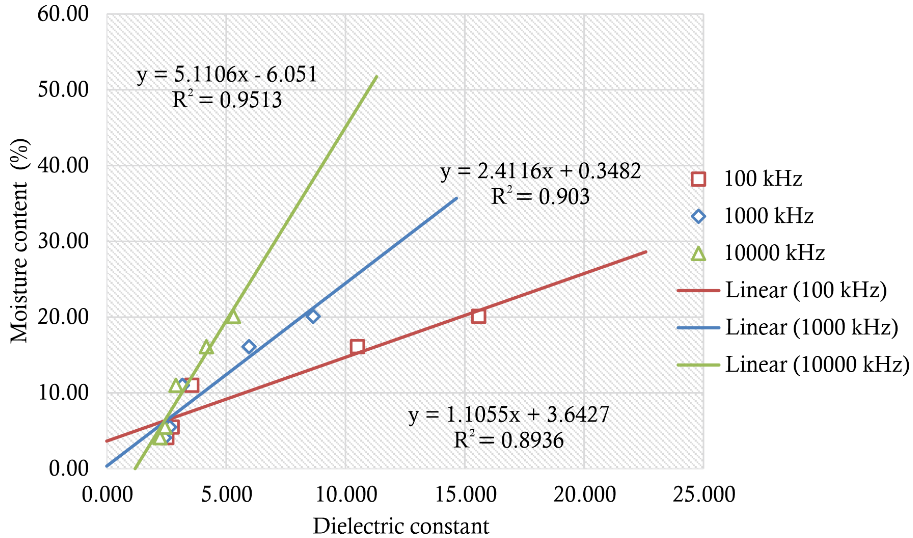

Fig. 5. Variation of dielectric constant with moisture content of barley seed

dependence of dielectric constant (Fig. 4). The value of dielectric constant of barley seed over the radio frequency range of 5-10000 kHz at different moisture content levels, averaged over the temperature range of 30-45 °C.

CONCLUSIONS

Developing high frequency moisture meter in microwave range is costly compared to radio frequency range and therefore real time barley seed moisture meter can be developed at a cheaper cost by using a real time permittivity or the dielectric constant measurement in radio frequency band in the neighborhood of 10000 kHz or 10 MHz, as study suggests. This study is also helpful in understanding the way the water is held in the barley seeds.

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